THE EFFECTS OF EUROPEAN SETTLEMENT ON THE BIODIVERSITY OF CHYDORID CLADOCERA IN BILLABONGS OF THE SOUTH-EAST MURRAY BASIN

Ralph W. Ogden

Division of Archaeology and Natural History, Research School of Pacific and Asian Studies, Australian National University, Canberra, ACT 0200, Australia

Abstract

Ogden, R.W., 1997. The effects of European settlement on the biodiversity of chydorid Cladocera in billabongs of the south-east Murray basin. *Memoirs of the Museum of Victoria* 56(2): 505–511

Assemblages of chydorid cladoceran headshields preserved in billabong sediments are analysed for changes in species abundance, richness and diversity from pre-European settlement to the present day. The fauna consists of at least 36 species. Species richness and diversity are lower in present day assemblages than before settlement, but this may be an artefact of increasing sedimentation rates. Although some species have declined markedly since European settlement, no definite extinctions have occurred. Chydorid Cladocera in billabongs may be pre-adapted to anthropogenic disturbance. Trends of decreasing abundance found in some species will need to be reversed if regional extinctions are to be avoided in the future.

Introduction

One of the aims of conservation is to preserve the biodiversity found in natural ecosystems. Normally, relatively undisturbed areas of an ecosystem serve as a benchmark for the natural biodiversity of the ecosystem. Knowledge of natural biodiversity is useful for a variety of purposes, including evaluating changes in biodiversity since European settlement, assessing how susceptible biota are to impacts from particular land use activities, identifying exotic species, and setting targets for ecosystem restoration.

Billabongs in the south-east Murray Basin contain diverse assemblages of invertebrates (Shiel, 1976; Shiel and Koste, 1983; Hillman and Shiel, 1991). However, farming and river regulation are so widespread in the Murray-Darling Basin that it is conceivable that there are no longer any billabongs in a pre European settlement condition to provide benchmarks for assessing the impacts of land use activities on biodiversity (cf. Walker and Hillman, 1977). Furthermore, the initiation of farming and other activities with the potential to affect biodiversity (e.g., fish introductions) preceded wide scale sampling of the region's invertebrate aquatic fauna (Ogden, 1996a).

In ecosystems such as billabongs that have been substantially altered by land use, fossil records provide an avenue for determining natural invertebrate biodiversity. Sediments deposited in slackwater areas preserve a record of resilient aquatic biota. The most common fossils are from species with calcium carbonate tests (e.g., ostracods, molluscs) or decay-resistant chitinous body parts (e.g., cladocerans, chironomids, trichopterans).

The billabongs in this study are found in the valleys of the eastern Murray River and the lower Ovens and Kiewa Rivers (figure 1). This region includes stretches of unregulated river (Murray River Lake Hume, Ovens and Kiewa Rivers) and regulated river (Murray below Lake Hume). Present day farming intensity on the floodplain is variable but generally decreases downstream for both rivers. Farming activity was probably more intense on the floodplain in the middle 1800's than it is today (Ogden, 1996a). In addition to farming and river regulation, billabongs and the surrounding landscape have been affected by the spread of rabbits (Murray-Darling Basin Commission, 1990) and four exotic fish species (Cadwallader, 1986), fertiliser use (Ogden, 1996a), logging and ringbarking of trees, and possible changes in the fire regime (Murray-Darling Basin Commission, 1990).

Changes since European settlement environmental have lead to a widespread decline in submersed aquatic macrophytes in large, deep (2–5 m) billabongs of the region (Ogden, 1996a, b). Macrophytes are still common in shallow billabongs and in smaller billabongs nearer the headwaters of rivers, but the ecotype of a large, deep billabong with a fringe of submersed macrophytes has been replaced by a phytoplankton dominated billabong (Ogden, 1996a, b).

Billabongs are small, shallow lakes occurring on floodplains, and are characterised by large fluctuations in physicochemistry associated with natural changes in depth and flooding (Briggs et al., 1985; Tan and Shiel, 1993; Ogden, 1996a). High levels of disturbance due to natural factors in billabongs may confer a degree of resistance or resilience of billabong invertebrates to anthropogenic disturbance (cf. Yount and Niemi, 1990). The aim of this paper is to investigate the effects of the loss of the deepwater, vegetated billabong ecotype, or other changes in billabongs in the post European settlement period, on the biodiversity of, both within billabongs and regionally. Fossils of the families Chydoridae, Macrothricidae, Bosminidae and Daphnidae are preserved in the sediments (Ogden, 1996a) but this paper is restricted to an analysis of the first two families only.

Methods

Sediment sampling and extraction of fossils
Sediment samples containing preserved Cladocera are from two sources. First, a single core was recovered from the deepest point in each of 7 billabongs (figure 1), and each core was subsampled for 1 cm sediment slices at various depths. Second, surface sediment samples (top 1 cm) from the profundal zone of 41 billabongs were obtained. Each surface sample consists of 3 subsamples that have been pooled. Ten of the billabongs are from the Murray River between Corryong, Victoria and Lake Hume, one from the Kiewa River, 22 from the Murray River between Lake Hume and Barmah Forest, and 8 from the Ovens River below Wangaratta. The locations of these billabongs are found in Ogden

Figure 1. The study region. The locations of billabongs from which sediment cores were recovered are shown.

(1996a). The cores were collected in 1992 and the surface sediment samples in 1993. The numbering of billabongs (figure 1) is based on a regional ecological survey (Ogden, 1996a). This system is retained for cross-referencing. The surface sediment samples come from a wider range of billabong types than the core-samples, which are from relatively deep (1.5–3.5 m), permanent-water billabongs only.

Cladocera were extracted from a 1–2 ml subsample of sediment. Details of the methods can be found in Ogden (1996a) or Frey (1986). Basically, the sediments were dispersed in hot KOH and the remains isolated by sieving and density separation. Slides were then prepared and the fossils are counted at 100x magnification.

Taxonomy
Headshields were used to differentiate chydorid species and identifications made by comparisons with published headshield illustrations or dissections of species collected from the study area. Many species have unique headshield morphometrics and pore arrangements (Frey, 1986), but some species, notably certain members of the genera *Chydorus*, *Biapertura*, *Alona* and *Ephmeroporus*, cannot be differentiated on the basis of their headshields (Ogden, 1996a). Headshields from such species are listed as undifferentiated or, if they appear to be closely related, assigned to species complexes.

Chronology
Billabong sediments deposited after c. 1870 are differentiated on the basis of the presence of pollen from the introduced tree genus *Pinus*. Settlement of the region by Europeans occurred in the middle 1800's, and trees of the genus *Pinus* were widespread and pollinating by 1870. Sediments lacking *Pinus* pollen are therefore considered to have been deposited before European settlement. ^{210}Pb dating in two cores has supported the use of *Pinus* as a postsettlement marker (Ogden, 1996a).

Counting, analysis and statistics
A minimum of 50 chydorid headshields per sample were counted. Species richness and Shannon diversity (using natural logs; Begon et al., 1986) of chydorid assemblages were calculated.

The chydorid species assemblages were pooled into 3 periods for comparison: recent (1993), postsettlement (1870–1990) and presettlement (pre-1870). The recent period is made up of headshields from surface sediment samples of 41 billabongs. Five sediment samples
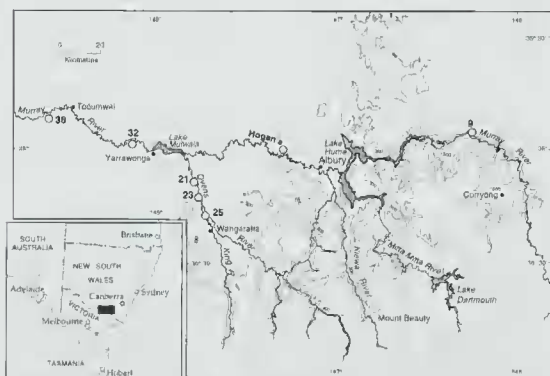
from three billabongs (numbers 23, 25 and 32) make up the postsettlement (1870–1990) period. Presettlement headshields are from 20 sediment samples deposited in 7 billabongs. For some analyses, presettlement assemblages were subdivided into upper presettlement (c. 1850) and lower presettlement samples (pre-1850). Presettlement samples are nearest, and pre-1850 samples furthest, in time-depth to the settlement boundary in cores. The pre-1850 samples are from six rather than seven billabongs due to preservation problems in the pre-1850 sample from billabong 21.

Differences in species richness and Shannon diversity of chydorid assemblages from recent, c. 1850 and pre-1850 time periods were investigated using linear mixed models. The random model was billabongs and observations within billabongs. The dependent variable in the fixed model was the assemblage measure (richness, diversity), and the independent variable the time period. An ANOVA was performed and the significance of the difference between means tested by calculating the F-probability of the variance ratio. For this analysis, the chydorid assemblages were restricted to the first 50 chydorid headshields encountered. Postsettlement (1870–1990) assemblages were excluded from modelling due to limited data.

Results

In all, 36 chydorid and one macrothricid species of are differentiated in the assemblages of headshields. The term 'species' here refers to both individual species and species complexes. Species richness is therefore probably underestimated. No attempt is made to identify the macrothricids to species since they do not appear to persist as fossils.

Increased decomposition is apparent in all cores following the onset of settlement, based on a loss of lustre and partial breakdown of some of the remains. The macrothricid remains appear to be quite susceptible to organic decomposition; they are quite commonly represented by the outer rim of the headshield only. However, none of the chydorid species that increase in abundance towards the surface appear to be exceptionally susceptible to organic breakdown or fragmentation. Furthermore, decomposition and other taphonomic factors have not significantly altered the overall proportion of body parts, or the degree of fragmentation, between recent, post and presettlement chydorid assemblages, based on ANOVA modelling (p=0.050; Ogden, 1996a).

Considering only chydorids, up to seven species are present in recent assemblages that are not found in the presettlement assemblages (table 1). However, four of these are doubtful due to taxonomic uncertainties. The two uncertain *Alona* species are more distinctive end members of species complexes. The *Rak/Chydorus* species is only represented by one headshield, and a 4-porate species by two headshields. These may simply be mutants of *Rak/Chydorus* and *Alona*, respectively. The 4-porate species does not resemble *Oxyurella*. In contrast, only one doubtful species is found in the presettlement assemblages that is not found in the recent assemblages (table 1).

Large shifts in the abundance of common species in the region are apparent with European settlement (table 2). Undifferentiated species of *Chydorus*, *Biapertura*, and *Alona* are relatively more abundant following settlement, at the expense of *Rak/Ephemeroporus* cx. 1 (hereafter called *Ephemeroporus* cx. 1), *Ephemeroporus* cx. 2, and *Alonella excisa*. The decline of *Ephemeroporus* cx. 1 is noteworthy. Only one *Ephemeroporus* cx. 1 specimen was found in 2889 headshields from postsettlement and recent assemblages, compared to 8% relative abundance before settlement.

Table 1. Chydorid species found exclusively in either recent or presettlement assemblages.

In recent assemblages, not in presettlement assemblages:	
taxonomy certain	**taxonomy uncertain**
Alona sp. 1	*Alona pulchella* sp.1
Alonella sp.1	*Alona diaphana* sp.1
Leydigia acanthocercoides	*Rak* or *Chydorus* species
	Unknown genus or 4-porate mutants of *Alona*
In presettlement assemblages, not in recent assemblages:	
	taxonomy uncertain
taxonomy certain	unknown genus related to *Alona*
none	

Table 2. Abundance of common chydorid species in each time period.

time period no. billabongs total count species	1993 41 2635 no.	%	1993 7 408 no.	%	1870–1990 3 254 no.	%	pre 1870 7 1169 no.	%
Chydorus undiff.	920	35	88	22	83	33	77	7
Biapertura undiff.	490	19	149	36	48	19	242	21
Alona undiff.	605	23	89	22	23	9	88	8
Rak/Ephemeroporous cx.1	1	~0	0	0	0	0	95	8
Ephemeroporous cx. 2	72	3	4	1	28	11	236	20
Alonella excisa	49	2	7	2	20	8	136	12

Table 3. Abundance of macrothric and minor chydorid species occurring in each time period.
Common species are excluded from calculations of the percentage of minor species.

time period no. billabongs total count CHYDORIDAE	1993 41 498 no.	% of minor species	1993 7 71 no.	% of minor species	1870–1990 3 52 no.	% of minor species	pre 1870 7 295 no.	% of minor species
Little change in relative abundance:								
Graptoleberis testudinaria	70	15.4	13	18.3	7	13.5	30	10.2
Biapertura setigura	22	4.8	2	2.8	1	1.9	13	4.4
Biapertura affinis	38	8.4	4	5.6	5	9.6	17	5.8
Biapertura sp. 7	10	2.2	2	2.8	2	3.9	9	3.1
Alona quadrangularis	47	10.3	13	18.3	10	19.2	28	9.5
Monope or Ephemeroporus	10	2.2	1	1.4	0	0	3	1.0
Pseudochydorus globosus	6	1.3	0	0	0	0	2	0.7
Daydaya macrops	8	1.8	2	2.8	1	1.9	2	0.7
Oxyurella sp.	4	0.9	1	1.4	0	0	5	1.7
Decreasing relative abundance:								
Biapertura sp. 1	20	4.4	2	2.8	6	11.5	38	12.9
Biapertura sp. 2	7	1.5	1	1.4	5	9.6	46	15.6
Biapertura sp. 3	1	0.2	0	0	0	0	10	3.4
Camptocercus australis	18	4.0	4	5.6	4 ·	7.7	48	16.3
Biapertura karua	9	2.0	0	0	2	3.5	32	10.8
Increasing relative abundance:								
Alona cf. *diaphana*	16	3.5	1	1.4	2	3.9	0	0
Biapertura sp. 5	10	2.2	3	4.2	1	1.9	1	0.3
Leydigia leydigi	28	6.2	10	14.1	1	1.9	2	0.7
Dunhevedia crassa	14	3.1	3	4.2	1	1.9	2	0.7
Leydigia acanthocercoides	14	3.1	7	9.9	1	1.9	0	0
Pleuroxis inermis	54	11.9	2	2.8	0	0	1	0.3
Kurzia cf. *latissima*	7	1.5	0	0	0	0	1	0.3
Alona cf. *puchella*	6	1.3	0	0	0	0	0	0
Alona sp.1	8	1.8	0	0	0	0	0	0
MACROTHRICIDAE								
All spp.	40	—	10	—	1	—	0	—

Of the 30 less common chydorid species, seven are too rare to detect trends with European settlement, and nine species change little in their relative abundance (table 3). Five species decrease in relative abundance following settlement, and nine species increase in relative abundance (table 3), although three of these are only found in recent sediments from billabongs that were not cored. Species with an increasing or decreasing trend in relative abundance usually have intermediate levels in 1870Â1990 assemblages. Macrothricid fossils are found in 19 of the 41 recent assemblages, and are absent from presettlement assemblages (table 3).

Species richness of presettlement assemblages ranges from 10–16 species and diversity is 1.35 to 2.35 based on 50 to 101 headshields per sample. Recent (1993) assemblages have on average 1–4 less species than presettlement assemblages (table 4) and have lower diversity (table 5). Species diversity and richness do not vary significantly between c. 1850 and pre-1850 assemblages (tables 4 and 5).

Discussion

Shifts in the dominance of species in cladoceran assemblages from before European settlement to the present day (tables 1–3) are indicative of environmental change in billabongs. Either a change in the dominance of chydorid species in living communities has occurred, or increased decomposition of remains following settlement has altered the make-up of assemblages. However, greater decomposition of postsettlement assemblages has not increased fragmentation, or changes the proportion of body parts, or differentially affected the appearance of any one chydorid species, suggesting that the taphonomic effects are minor.

Historic increases in the dominance of *Chydorus sphaericus* have been considered as evidence for eutrophication in some northern hemisphere lakes (Frey, 1986). This may be the reason behind the increased dominance of undifferentiated *Chydorus* following European settlement (table 2). Indeed, several chydorid species have been found associated with floating material, including some indicators of eutrophication such as *Azolla* and floating algal mats (pers. obs. and Russ Shiel, pers. comm., 1996). However, chydorids were rare in the numerous plankton samples taken in the course of a limnological survey of billabongs (Ogden, 1996a), lending support to Shiel's (1976) opinion that they are littoral strays.

Species richness and diversity are lower in present day chydorid assemblages than in presettlement assemblages. Sedimentation rates appear to have increased postsettlement (Ogden, 1996a), so it is likely that the surface assemblages accumulated in a shorter time span than the presettlement assemblages. The presettlement samples may have more species because they represent longer time-slices than the surface assemblages, and compaction of deeper sediments accentuates this effect (Smol, 1981). Decreases in richness and diversity from presettlement to recent assemblages are not great enough to conclude they translate to differences in chydorid communities living at the time. At the least, though, it can be concluded that the richness and diversity of chydorid communities have not *increased* since settlement.

A number of species occur in present day billabongs that are not found before settlement (tables 4 and 5). There are three possible explanations: low preservation potential of these species, sampling of a broader range of billabong types for present day cladoceran assemblages compared to the 7 billabongs sampled for their presettlement assemblages, and the introduction of exotic species.

The macrothricid provide an example of taxa that do not preserve. Macrothricid headshields are reasonably common in surface sediments but are almost never found in deeper sediments (table 3), and where present, are usually decayed. As already noted, variation in the relative preservation potential of individual chydorid species is not readily apparent.

Pleuroxus cf. *inermis* is an example of a species that normally inhabits a billabong type different from those that were cored. The cored billabongs are all relatively deep, permanent water sites. *Pleuroxus* prefers shallow, ephemeral billabongs. Notable occurrences elsewhere are the Albury sewage treatment lagoon (Ogden, 1996a) and Pleistocene sediments from Cuddy Springs, NSW (pers. obs.). *Pleuroxus* cf. *inermis* therefore appears to thrive in highly disturbed billabongs, unlike the sites chosen for coring. *Kurzia* cf. *latissima*, *Alona* cf. *puchella* and *Alona* sp. 1 also seem to favour environments not found in the cored billabongs.

In contrast, *Alona* cf. *diaphana* and *Leydigia* sp. 2 (table 4) are fairly widespread, and occur in the cored billabongs and other deep or permanent-water billabongs. They are candidates for postsettlement introductions into the study region.

Table 4. Mean species richness of cladoceran assemblages.

number of billabongs	mean richness			difference in means ± 2 s.e.	prob.
	1993	ca. 1850	pre 1850		
7	8.9	11.3		2.4 ± 1.4	0.015
6	8.3		12.7	4.3 ± 2.2	0.010
6		11.2	12.7	1.5 ± 1.8	0.165

Table 5. Mean species diversity of cladoceran assemblages.

number of billabongs	mean diversity			difference in means ± 2 s.e.	prob.
	1993	ca. 1850	pre 1850		
7	1.55	2.08		.53 ± .23	0.003
6	1.51		2.07	.56 ± .36	0.028
6		2.05	2.07	.02 ± .28	0.922

Regional biodiversity of the Chydoridae in billabongs has either increased or remained steady since European settlement. Species introductions may have been offset by regional extinctions in the *Ephemeroporus* complex 1. This complex is almost certainly composed of more than one species, based on major and minor pore arrangements (Ogden, 1996a), and yet only one headshield of this complex was found in over 2600 headshields identified from surface sediments. Some members of *Ephemeroporus* complex 1 have probably gone extinct in the region.

The relatively small changes in regional biodiversity since European settlement are noteworthy in light of the intense utilisation of the floodplain and the regional decline of macrophytes in deeper billabongs (Ogden, 1996a, b). Significantly, the single *Ephemeroporus* complex 1 headshield was found in one of the few remaining large, deepwater, vegetated billabongs left in the region. Overall, though, the regional diversity of chydorid does not appear to have suffered much from the loss of the 'large, deepwater, vegetated' billabong ecotype. It is possible that the chydorids were preadapted to the changes that occurred with settlement (Yount and Niemi, 1990) due to high levels of natural disturbance in billabongs (cf. Brock, 1986; Ogden, 1996a).

In spite of presettlement regional chydorid biodiversity remaining intact, there is good reason to suspect that this situation will not persist. The reduction in abundance of some species and species complexes, such as *Ephemeroporus* complex 1, *Biapertura karua* and *Biapertura* sp. 3 appears to follow a declining trend through time. If this trend continues, some of the species will become regionally extinct.

Conclusions

Species richness and diversity of chydorid may have declined in billabongs after European settlement, but the possibility that this pattern is an artefact of increasing sedimentation rates cannot be eliminated. Overall, the biodiversity of chydorid has changed very little in billabongs of the south-east Murray Basin since European settlement, which is remarkable given the environmental impacts to billabongs in that time. This suggests a large degree of flexibility in the life strategy of chydorids in billabongs, possibly due to billabongs having a large amount of natural disturbance. However, some species are gradually declining in regional abundance, and if this trend continues, regional extinctions can be expected.

References

Begon, M., Harper, J.L. and Townsend, C.R., 1986. *Ecology: individuals, populations and communities.* Blackwell Scientific Publications: Oxford.

Briggs, S.V., Maher, M.T., and Carpenter, S.M., 1985. Limnological studies of waterfowl habitat in south-western New South Wales. I. Water chemistry. *Australian Journal of Marine and Freshwater Research* 36: 59–67.

Brock, M.A. 1986. Adaptations to fluctuations rather than to extremes of environmental parameters. Pp. 131–140 in: de Deckker, P. and Williams, W.D. (eds), *Limnology in Australia.* CSIRO, Dr. W. Junk: Melbourne.

Cadwallader, P.L., 1986. Fish of the Murray-Darling system. Pp. 679–694 in: Davies, B.R. and Walker, K.F. (eds), *The ecology of river systems.* Dr. W. Junk: Dordrecht.

Frey, D.G., 1986. Analysis. Pp. 667–692 in: Berglund, B.E. (ed.), *Handbook of Holocene palaeoecology and palaeohydrology.* John Wiley and Sons.

Hillman, T.J. and Shiel, R.J., 1991. Macro- and micro-invertebrates in Australian billabongs. *Verhandlungen Internationale Vereinigung Limnologie* 24: 1581–1587.

Murray-Darling Basin Commission, 1990. *River Murray riparian vegetation study.* Murray-Darling Basin Commission: Canberra.

Ogden, R.W., 1996a. *The effects of farming and river regulation on billabongs of the eastern Murray River and lower Ovens River.* Unpublished PhD thesis. ?University.

Ogden, R.W., 1996b. Potential for the restoration of aquatic macrophytes in billabongs. Pp. 99–104 in: Rutherfurd, I. and Walker, M. (eds), *Proceedings of the First National Conference on Stream Management in Australia.* CRC for Catchment Hydrology.

Shiel, R.J., 1976. Associations of entomostraca with weedbed habitats in a billabong of the Goulburn River, Victoria. *Australian Journal of Marine and Freshwater Research* 27: 533–49.

Shiel, R.J. and Koste, W., 1983. Rotifer communities in northern and south-eastern Australia. *Hydrobiologia* 104: 41–47.

Smol, J.P., 1981. Problems associated with the use of 'species diversity' in paleolimnological studies. *Quaternary Research* 15: 209–212.

Tan, L.-W. and Shiel, R.J., 1993. Responses of rotifer communities to inundation. *Hydrobiologia* 255/256: 361–369.

Yount, J.D. and Niemi, G.J. 1990. Recovery of lotic communities and ecosystems from disturbance: a narrative review of case studies. *Environmental Management* 14: 547–569.

Walker, K.F. and Hillman, T.J., 1977. *Limnological survey of the River Murray in relation to Albury-Wodonga, 1973-1976.* Albury Wodonga Development Corporation: Wodonga.